the course of a few years, Fresnel succeeded in giving simple and complete explanations of all known optical phenomena, including polarization, in taking for granted that light results from waves, the vibrations of which are transverse to the direction of propagation. In the case of polarization, these vibrations remain in a fixed plane; in ordinary light, they radiate in all directions. Fresnel brought around to his views almost all former believers in the emission theory and was elected to the *Académie* in 1823. The wave-theory of light, as he constituted and mathematically developed it, ruled in optics, without reservations, all through the nineteenth century.

Fresnel, when elected to the *Académie,* was only thirty-five years old. Unfortunately, his health was gravely impaired and forbade him intensive work. Appointed in the Department of Public Works to the commission on lighthouses, he radically modified the construction of the lights in use and very much increased their power by the invention of the lens belt which is still in use. This invention, which has rendered such great service, was his last piece of work. He died in 1827, at the age of thirty-nine. His amazingly fruitful activity hardly extended beyond 12 years. This was enough for him to completely renew optics; besides, through his conception of the transverse vibrations of light, his work was to have a momentous influence on other parts of physics and mathematics.

Ampère and the Creation of Electrodynamics.

The same years during which Fresnel was doing his work also witnessed, in France, the birth of a new science, electrodynamics, which was in the nineteenth century, and still is to-day, of unequaled importance, both in theoretical science and practical life.

In the eighteenth century, we saw the first and feeble rise of the science of electricity, still limited to the

field of electrostatics. Electricity was then produced only by friction on non-conductors or by induction on insulated conductors; in both cases, the discharge came through sparks. The laws of these phenomena had been experimentally established by Coulomb, from 1785 to 1789, by means of the torsion balance. But, interesting as these studies may have been, electrostatics, from the experimental point of view, did not lead later on to considerable advances nor applications. Quite different results were attained in electrodynamics, the science of electric currents flowing through conductors. Electricity accumulated on a body in a static condition causes, at the moment of discharge, an instantaneous current, which, however, on account of its extremely short duration, cannot be studied. The study of currents, therefore, could not begin before the invention of the pile, by the Italian physicist Volta, in 1800. Bonaparte, as First Consul, paid a solemn tribute to this great invention by inviting Volta to come to Paris and repeat his experiments before the *Académie des Sciences* and by showering him with honors. The applications of the pile were, at first, made mostly in England, where the great chemist Davy isolated by the means of a powerful battery the two alkaline metals, potassium and sodium, of which Lavoisier had foreseen the existence; Davy also discovered the electric arc. For this important work, Davy, in spite of the state of war between France and England, received from the *Institut* the great award granted by the First Consul.

In 1819, the Danish physicist, Oersted, in turn, made the unexpected discovery that the passage of the current flowing from the pile through a conducting wire deflected a magnetized needle placed in the vicinity of the wire, the needle tending to take a position perpendicular to the wire. This caused great astonishment and served as a starting point to the researches

of Laplace, Savart, Biot and, above all, of Ampère, who was going, in a few weeks, to build up the science of electrodynamics.

Ampère.

André-Marie Ampère (1775-1836) is, at the same time, one of the greatest and most attractive personalities of science.[1] Born in Lyons, brought up in the village of Poleymieux, where his father, an admirer of J. J. Rousseau, was his first and almost only teacher, forming his son's mind without any compulsion, Ampère successively developed a passionate interest in the most divers sciences of his time, as well as in literature, philosophy and poetry. He pursued all those studies by himself. The Revolution suddenly upset his life. His father was guillotined at Lyons, in 1793.

After a long period of complete prostration, Ampère pulled himself together, earned a living, at first, by giving private lessons in mathematics and physics, then became a professor at the *lycées* of Bourg and Lyons. In spite of isolation and material difficulties, his thought was active. A remarkable memoir which he published in 1802, on problems of probability, in reference to games of chance, drew the attention of the astronomers Lalande and Delambre. Soon after, he lived in Paris, first as a *"répétiteur,"* then as a professor at the *École Polytechnique;* in a few years, his works in mathematics brought about his election to the *Académie des Sciences* (1814). Alone, they would suffice to put him in the ranks of the greatest mathematicians of the beginning of the century. But we shall see later that, during this same period, he was formulating capital views on chemistry and the

[1] On the most interesting personality of Ampère and the events of his life, see the book of M. L. de Launay: *Le grand Ampère,* Paris *(Perrin),* 1925.

molecular theory of gases. However, his chief claim to glory was to come out from the experiment through which the Danish physicist, Oersted, in 1819, discovered the action of electric current on a magnetized needle. This experiment became known in Paris only on September 4, 1820, when Arago, who had witnessed it in Geneva, in de la Rive's laboratory, reproduced it himself before the *Académie*. Through an intuition of genius, Ampère, in a few days, identified magnetism and electricity. He worked in a fever of which his memoirs and his letters to his son reveal the ardor.[1] From September 18th to November 6th,

A.-M. Ampère

[1] Here is a passage from his memoirs which will give us an idea of this creative fever, as well as of the speed and depth of his insight. It concerns his first paper, the one he wrote for the meeting of the *Académie* on September 18: *"Je décrivis les instruments que je me proposais de faire construire et, entre autres, des spirales et des hélices galvaniques. J'annonçai que ces dernières produiraient, dans tous les cas, les mêmes effets que les aimants. J'entrai ensuite dans quelques détails sur la manière dont je conçois les aimants, comme devant uniquement leurs propriétés à des courants électriques circulant dans des plans perpendiculaires à leur axe et sur les courants semblables que j'admets dans le globe terrestre, de sorte que je réduisis tous les phénomènes magnétiques à des effets purement électriques."** * One may see, in some degree, the flash of genius suddenly illuminating the new world of electromagnetism.

* "I described the instruments which I proposed to have built, and among others, galvanic spirals and helices. I announced that these last would produce in every case the same effects as magnets. Afterwards, I entered into some details about the manner in which I conceived of magnets as deriving their properties solely from electric currents flowing on planes perpendicular to their axis and about similar currents, the existence of which I admit in the terrestrial globe, so that I reduced all magnetic phenomena to purely electrical effects."

from week to week, his communications followed one another regularly and fixed the laws of electromagnetism. The crucial experiments which established them were made in his apartment, the only laboratory at his disposal, with apparatus built with his own hands, on a table which is to-day a precious relic preserved at the *Collège de France*. Like many others of the greatest creators of French science, Ampère brought forth his capital discoveries in a penury verging almost on misery. From these was born, in the course of a few weeks, a complete, new and fundamental science, the most fertile in its applications. Already Ampère derived from it the solenoid, the electromagnet, the principle of the telegraph, and a few years later he inspired the machine builder, Pixii, with the idea of the first electromagnetic machine.

Linking, without delay, mathematical study with experimentation, Ampère presented a synthesis of his researches in a *Mémoire sur la théorie des phénomènes électrodynamiques uniquement déduite de l'expérience* which appeared in 1827, in the *Mémoires de l'Académie*. To appreciate the import of Ampère's work, it is enough to quote J. C. Maxwell, whose genius established the electromagnetic theory of light: "The researches by which Ampère established the laws of the mechanical forces electric currents exert on each other stand out among the most brilliant achievements ever reached in science." Maxwell calls Ampère the Newton of electricity.

Another capital discovery, made almost immediately after, completed those of Ampère and perfected that marvelous tool, electrodynamics; this was the discovery of induction. It was the work of an Englishman, Faraday, and was made in 1831; it led to the dynamo and this is enough said to measure its importance. Later on, besides, the discovery of induction led to considerable consequences in the general theoretical

conception of magnetic and electrical actions; it prepared the work of Maxwell, which is the preface to all contemporary physics.

Sadi Carnot and the Principles of Thermodynamics.

In the period under review, French physics produced a third achievement, the results of which have been no less important. This time, the work was in the field of heat. On this subject, a series of discoveries, the consequences of which developed but gradually, were made in France in the first twenty years of the new century. We have already noticed in passing, at the end of the eighteenth century, the works of Lavoisier and Laplace, who founded calorimetry, in defining more clearly the notion of quantity of heat, and those of Fourier, which resulted, in 1818, in his *Théorie analytique de la chaleur*. The physical study of gases was to introduce fruitful data and ideas. Gay-Lussac (1778-1850) equally renowned as a chemist and a physicist, in 1806, made the surprising observation that all gases dilate according to the same law; they have the same coefficient of dilatation; on the other hand, Gay-Lussac established that there is always a simple ratio between the volumes of combining gases, as well as between such volumes and that of the gaseous compound obtained. An Italian man of science, Avogadro, in 1813, deduced from this the all-important consequence that, at the same pressure and temperature, equal volumes of all gases contain the same number of molecules. This idea has now been verified by various experimental methods, and one has been able to measure with sufficient accuracy the number of these molecules; this is called the Avogadro's number. Let it be said, in passing, that Ampère, without knowing Avogadro's work, had drawn the same conclusion in a memoir published in 1814.